Comparative Study of Rock Joints With and Without Gouge Filled Material

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Comparative Study of Rock joints with and without Gouge Filled Material

Thesis submitted in partial fulfillment

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in

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by

Soumendra Kodamasingh

(Roll Number: 215CE1015)

based on research carried out

under the supervision of

Prof. Nagendra Roy

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Supervisor's Certificate

This is to certify that the work presented in the thesis entitled "***Comparative Studies of Rock Joints With and Without Gouge Filled Material***", Roll Number 215CE1015, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements for the degree of *Master of Technology in Geotechnical Engineering.* Neither this thesis nor any part of it has been submitted earlier for any degree or diploma to any institute or university in India or abroad.

Prof. Nagendra Roy

Dedicated to my lovable parents

Declaration of Originality

I, Soumendra Kodamasingh, Roll Number 215CE1015 hereby declare that this thesis entitled "***Comparative Studies of Rock Joints With and Without Gouge Fill Material***" presents my original work carried out as a postgraduate student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the thesis. Works of other authors cited in this thesis have been duly acknowledged under the section "Reference". I have also submitted my original research records to the scrutiny committee for evaluation of my thesis.

I am fully aware that in the case of any non-compliance detected in future, the senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present thesis.

May, 2017

NIT Rourkela Soumendra Kodamasingh

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May, 2017 *Soumendra Kodamasingh*

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Abstract

In rock system the particles are jointed irregularly. These discontinuities in joints may occur with or without gouge filled material. The discontinuity in rock decides the strength of the rock mass. However, the strength test of these joints is costly and not easy to execute at rock sites. This opens the avenue for the development indirect method which computes the rock strength.. we can calculate the strength of the rocks by knowing some factors these are roughness parameter, joint factor inclination parameter. By knowing the joint factor value we can evaluate the strength of rocks. Joint factor totally depends upon roughness parameter joint number. Plaster of Paris specimens were made for experiment.Calucalte the strength of rocks and also experiment different specimens with various angle of orientation (β^0) which is varying from 0^0-90^0. These models were Possessing joints with and without gouge fill. Mica with Plaster of Paris used as the gouge material. Here, an attempt was made to compare the results of strength and deformation characteristics of jointed rock mass with and without gouge fill by using model material plaster of Paris. From the experiments it was found that for single jointed rock mass specimen without gouge fill at $\beta= 30^0$ strength was found to be 0.66 MPa which is minimum and at $\beta= 90^0$ strength was found to be 7.6 MPa which is maximum. An empirical relationship $\sigma_{cr}= e^{-0.008 \times J_f}$ is applicable for joints with gouge. And production of equation for the relation between compressive strength ratio with joint factor. it was observed that the equation created from experimental values is similar to predicated equation given by Arora.

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Nomenclature

Jn	**joint frequency**
n	**inclination parameter**
r	**joint strength parameter**
σnj	**the normal stress on the joint**
σcm	**compressive strength of the composite specimen;**
σce	**compressive strength of the element constituting the block;**
L	**length of the specimen;**
l	**length of rock element;**
σc	**compressive strength;**
Ed	**deformation modulus;**
υ	**Constant**
$\sigma 3$	**confining pressure,**
Pa	**atmospheric pressure**
K	**modulus number**
Mrj	**modulus ratio**
σcr	**uniaxial compressive strength ratio**

σ_{cj}	**uniaxial compressive strength of jointed rock**
σ_{ci}	**uniaxial compressive strength of intact rock.**
Jf	**joint factor**
Er	**elastic modulus ratio**
E_{tj}	**tangent modulus of the jointed rock**
E_i	**tangent modulus of the intact rock**
φ_r	**the residual angle of friction**
u	**the water pressure.**
σ_n'	**the effective normal stress**
c	**Cohesion**
φ	**friction angle**

Chapter 1

Introduction

1.1 Introduction

In rock system the particles are jointed irregularly. These discontinuities in joints may occur with or without gouge filled material. The discontinuity in rock decides the strength of the rock mass. However, the strength test of these joints is costly and not easy to execute at rock sites. This opens the avenue for the development indirect method which computes the rock strength. In present study, We compared the strength of joints with and without gouge filled material on the basis of uniaxial compressive strength (UCS) variation accordingly with a parameter named joint factor (J_f). The Joint factors are computed form the pictures of rock site taken at various angles of inclinations. This would save time and can predict the rock stresses mass without the design of jointed rock mass. Furthermore the discontinuity rock specimens are difficult to get from the field and take it to the lab for testing. Particularly the testing of large specimens is quite time taking and expensive, therefore the single come up would be to determine the influence of joints and their alignment on stress directions and the strength. The first attempt made by Hoek and Brown (1980) characterized the jointed mass by material parameters viz. m_j and s_j using the field and laboratory data of Punguna andesite. Next attempt was made for more realistic one, the assessment of rock strength using extensive laboratory tests were conducted by Yaji 1984, Arora 1987, Roy 1993, and Singh 1997 using plaster of Paris, sandstones, granite and sand –lime bricks. in

. After assessing the uniaxial and triaxial tests the following important factors was found to effect the strength

- Joint frequency
- Critical joint alignment
- The strength along the critical joint. The combined effect of these three factors has been represented by the joint factor as (Ramamurthy 1993, Ramamurthy and Arora 1994).
- Joint factor

$J_{f}= J_{n}/ (n*r)$

- Where J_n represents joint frequency, n is the slope parameter related to critical joint and r is the joint strength parameter. The values of n were gained through the ratio of log (strength reduction) at $\beta = 90^{o}$ to log (strength reduction) at the preferred value of β. The analysis determined the same value of for all joint frequency. The joint strength parameter, $r= (\tau_j / \sigma_{nj}) = \tan \varphi_j$, is acquired from shearing test along the joint where τ_j is shear strength along the joint ,σ_{nj} is the normal stress on the joint , and φ_j is the equivalent value of the friction angle.

The value of r depends on the uniaxial compressive strength of the rock amid absence of shear tests. The Gouge is clay like material that forms between the fault walls by the movement along the fault surface as per (ISRM, 1978, dictionary of geological terms, 1962). Geological method and tectonic activities is solely responsible for the rock discontinuity. As in the tropical countries, the intensive weathering affects the interior part of the rock masses. Joints provide the passage for flowing of water and other weathering agents. This makes material of the joint surface disintegrated and decayed to form a completely weathered material which is much weaker than the intact rock. An entire weathered material is inserted in joint blocks. The enduring of joint surface and situ deposition directs the development of a “filled joint”. The contact nature between the joint surfaces interface and infill produces intricate filled joints deformation. The Filled joint holds high deformability with low shear strength when the load is applied. These undesirable features hinders any civil engineering constructions while digging the rock mass, which will induce the instability in the excavated surface. The present study deals with the strength evaluation of joints with and without gouge fill.

Chapter 2

Literature Review

2.1 Introduction

In this part we were discussing about the literature we already have studied to improve or strengthen the idea about the thesis and got knowledge about the topic so that it gave a lot of idea about the topic. First of all we have collected a lot of literature review to use this literature review to improve the thesis we have studied literature about different areas just like:

- Uniaxial compressive strength
- Shear strength of rock joints
- Modes of failure in jointed rocks
- Surface roughness
- Thickness of infilling
- Particle shape of infill material
- Filled joint elements

2.2uniaxial compressive strength

Walsh (1965): uniaxial elastic compression test of rock is analyzed by non-linear stress strain behavior and hysteresis. Due to this two effect we can analyze the cracks on the rock. If we take two models by some isotropic material one with some cracks inside the specimen and another specimen without cracks. it was observed that young's modulus of crack specimen was less than the specimen of another specimen.

Adams (1994): To quantify the quality of an agglomerated item most importantly pack a bed of the agglomerates by utilizing a cylinder in an rigid chamber; it is known as a confined uniaxial compression test. A straight forward investigation of this compression procedure is displayed, regarding the framework as absolutely dissipative and applying the Mohr—Coulomb naturally visible disappointment measure. This empowers normal single agglomerate qualities to be found from the intial disfigurement conduct of agglomerates bed.

Li and Xia(2000): We can find the strain history of rock specimen when it undergoes deformation when the load was applied in a cyclic way on the rock specimen .creep on the rock specimen was found by uniaxial compression creep test by creep testing machine. According to the author they were conducted uniaxial compression creep test and relaxation test on four different types of rocks. The test values were compared and the value of strain rate we can find and limit strain can be known.

Cargill and Shakoor(1990): According to literature Eight sandstones, three limestone's, one dolomite, one marble and one syenitic gneiss were tested for uniaxial compression test. To find the relation between the each type of specimen for uniaxial compressive strength. Again there was a lot of test was conducted just like the point load, the Schmidt hammer, the Los Angeles abrasion, and the slake durability tests. For point load test ten rock samples were used and for Schmidt hammer test same procedure were used . but for slake durability and los Angeles abrasion test maximum three sample was enough. by correlating the result of different test we can find the relation of different test

Hayashi(1966): according to literature if we make two specimen of plaster of paris and test the specimen for uniaxial compressive strength.one with joint in the specimen another specimen without joint then intact specimen have more uniaxial compressive strength than the jointed specimen.and another thing if the number of joints on the specimen increases then the uniaxailcompressive strength decreases.

2.3 Shear Strength of Jointed Rocks

Barton and Chaubey et al (1977): according the paper they derived the empirical relation for rock joints to find the shear strength property of the rock specimen. So therefore they required three parameters to evaluate or predict the shear strength. These three parameters are joint roughness coefficient (*JRC)*, the joint wall compressive strength (*JCS)*, and the residual friction angle (φ_r) .if the joint length increases then the value of JRC AND JCS reduces and shear strntgh of the specimen decreases and shear stiffness decreases.

Byerlee and PAGEOPH (1978): According this literature at low normal stress the required shear stress to move the rock along joints varies differently in various type of rocks. And it is totally depends upon surface roughness of the joint. But at high normal stress the the shear stress required for joint for different rock nearly equal.

2.3 Modes Of Failure Of Jointed Rocks

Brown(1970) :according to literature first took a plaster of Paris specimen with continuous joint and intermittent joints made a triaxial compression test and found the modes of failure basically axial cleavage and splitting failure occurs.

2.4 Surface Roughness

Brady and Brown(1985): Surface roughness is the measure of unevenness and wavy plane in rock mass .when in a rock mass the two joints are there if compression was applied then the planes are depend on surface roughness. It was the measure factor for determining the shear strength of joints.

2.5 Thickness Of Infilling

Pereira (1990): thickness of infilling was main important work in a joint .in this literature the author studied the infilling material and filler thickness was the two times the size of the grain size. And studied the rolling ,motion of the grains when the load was applied the grains roll through the contact with the plane of the joint and grains are there to obstruct the motion of the grain and all grains are contact with each other to fill the void in the filler

2.6 Particle Shape Of Material

Holubec and D'Appolonia ,(1973):author studied the effect of size of the particle on granular soil .when the particles are angular in size the void ratio i.e. maximum and minimum was increasing with angularity. When the particles were angular then the shear strength and friction angle was increasing.

Feda (2002): According to feda when the particles were angular then the dynamic penetration of the soil increases and it was found that the crushable character increases.

2.7 Filled Joint Elements

Mohd Amin et al. (2000): the author describes about granite rock and the filled joints formed in that rock due to continuous weathering. If the joints were water permeable the water enter in to the joint and it expand volume of the rock because of less stable feldspar and mica react with water and expands.

Chapter 3

Theory

3.1Engineering Description Of Rock

Rock is the first earth material was discovered by geologist. Rock and soil was first differentiated by an engineer, but some time the division is not properly studied. An engineer can differentiates between the rock and soils by imposing force on them or by construction. .the study of soil by imposing reaction on the soil is called as soil mechanics and by imposing reaction on rock is called as rock mechanics. Rock and soils are made up of mineral and organic particles. Soils are made up of mineral just like kaolinite, montmorillonite. The rock is made up of mineral and particle cemented together to from hard solid rock. So rock mechanics is necessary to know the behaviour of rock deformation fracture and joints.

3.2 Rock Properties

(I)**JOINT:**

Collection of some parallel joints is known as joint sets to from joint structure. Joints are various types just like be open joint and filled joints .in an open joints when water enters in to the structure then the rock suffers a severe crack on the structure.

(ii) **FAULT:** fault is planar fracture in a rock and the fracture ranges from few meters to few kilometres in width.

(iii) **DISCONTINUITY:** it is main term for joints and joints parallel to bedding planes. It describes the discontinuity in the bedding plane. To describe discontinuity following factors are described.

(a) **Spacing:** Perpendicular distance between adjacent joints is called as spacing.

(b) **Roughness:** It is the surface roughness and waviness of rock joint. And it provides shear strength to the rock.

(c) **Aperture:** An intervening space is air or water filled between two rock walls of a discontinuity.

(d) **Filling:** in a rock if there is some discontinuity then the space is filled by some filling material just like clay, sand, cement. etc. to develop some strength.

(e) **Seepage:** Water stream and moisture were visible in the rock discontinuity and rock.

3.3 Gypsum Plaster:

Plaster of Paris is a building material used for the protection and decoration of walls and ceilings decorative elements were made by putting plaster of paris with some moisture content. Inside a mould. When plaster of Paris was added with some water then some heat was generated. The chemical equation is

$CaSO4.H2O \longrightarrow 2CaSO4.0.5H2O + 3H2O$

Gypsum was created when plaster of Paris was mixed with water.

3.4 X-Ray Diffraction Analysis

in this method first of all some constant wave length was applied on a sample to know the crystal structure of the sample . X-rays were diffracted by the lattice of crystal structure which was present in the sample. And result coming were crystal gave peak a special pattern of reflection at various angles. Strength and Deformation Behaviour of Jointed Rock Mass studied from this. Plaster of paris was tested and crystalline structure present in it diffracted in unique pattern. At some glancing angle of x-raybeam.in the graph a unique pattern of diffraction peaks and the glancing angle it may be 2Θ and Θ

3.5 SEM

SEM means scanning Electron Microscope .it magnifies the various types of material. In the present case we used SEM to study the plaster of Paris specimen. It magnifies x1000, x2000, x30000 and gave the microstructure of the specimen and gave the structural description about the material. And it was shown in figure(5.2 to 5.7).

3.6 Uniaxial Compressive Strength:

Calculate the compressive strength of the jointed rock and calculate the compressive strength of intact rock and take the ratio of both then we can get the value of uniaxial compressive strength ratio

$$\sigma_{cr} = \sigma_{cj}/\sigma_{ci}$$

σ_{cr} = compressive strength ratio

σ_{cj} =compressive strength of jointed rock

σ_{ci} = compressive strength of intact rock

3.7 Intact Rock Mass

Intact rock is in which there is no defect and the rock is isotropic and homogeneous and it fails suudenly.thats why it is brittle in nature.

3.8Joint Roughness

It is the surface roughness and waviness of rock joint. And it provides shear strength to the rock.

Chapter 4

Laboratory investigation

This section deals with shear strength testing and determination of deformation properties in rock joints. It also involves the experimental procedure including material used, preparation of specimens and Making joints in the sample treated.

4.1 Materials used

Over the years, scholars and researchers' have treated plaster of Paris as a material of model for imitating weak rocks. This plaster of Paris holds simple casting procedure, as it is flexible and gets harden in minimum time. Moreover, it's easy availability and low cost constitutes this material suitable for modelling the rocks material and joints. Accordingly, In Geotechnical Engineering, Plaster of Paris is considered to be the perfect materials for modelling the rocks as it resembles the pattern of its strength and deformation. In our present work, we have follow the same tradition and used mica and Plaster of Paris as a gouge material.

FIGURE-4.1 Plaster of Paris Sample

4.2 Specimens preparation

Firstly, we blended two packets of plaster of Paris in a compartment. The compartment was sealed by a plastic at the top followed by placing two polythene coatings. We prepare number of samples with several rate of refined water going along with the earlier procedure of preparation. These samples are tested for uniaxial compressive strength. The specimen with maximum uniaxial compressive strength was chosen to be the best sample, and later were prepared with same proportion of moisture. The water content in the perfect sample chosen was found out to be 32 percent. After that identical paste was prepared in a bowl and shifted it into a mould in the layer of three. Care must be taken during the transfer of paste, as table in which the sample is prepared keeps on vibrating at nearly two minutes. Vibration is supplied to mould for proper compaction, this will produce the specimen air void free. Finally specimen was drawn from the mould using extruder. We prepared all the testing sample with same procedure of preparation and 32 percent moisture. These sample were left at room temperature for 48 hours.

4.3 Curing

We prepared the even solution of concentrated sulphuric acid (47.7cc) blended with distilled water (52.3 cc). All the prepared specimens were placed in the desiccators filled with the solution for curing, this process of curing will bring in constant weight in all the samples. After curing these specimens were reduced to the length of 76mm followed by polishing with sand Each plaster of Paris sample was made with uniform (L/D) ratio i.e. 2: 1 (in our sample L = 76 mm and D= 38 mm).

FIGURE-4.2   Curing of Specimen

4.4 Making joints in specimens

The following accessories were used for constructing rough joints

1. Pencil

2. Scale

3. Light weight hammer

4. Chisel

5. Protractor

6. “V” block

Two longitudinal lines were drawn, inverse to each other, the sample facade. Ensuring the introduction angle regarding the focal longitudinal line is done with protractor. The sample was Stamped with "V' piece using Chisel and mallet. We followed the same process for stamping the various sample at several angle. Joint framed looked like like rough joint.

FIGURE-4.3 “V” Block

4.5 Experimental setup and test procedure

In the present work, the prepared Plaster of Paris samples were tested under uniaxial compression to delve into the deformation behaviour and examining the change in shearing parameters. These tests were conduct accordingly to the ISRM and ARE codes. The main objective of such uniaxial compression test is to obtain the compressive properties of jointed rock mass at several angles from 0 to 90 degrees with the break of 10 degrees. The compression tests were conducted for two situations

i. Rock joints with gouge fill

ii. Rock joints without gouge fill

At this point, Mica with plaster of Paris with 3mm thick gouge is exercised.

4.6 Direct shear test

This test was conducted to realise the joint roughness($r = \tan\varphi$) during shear of joints. We used customary direct shear test device (IS: 1129, 1985) provided with specific. Two separate wooden pieces of size 59mm x 59mm x 12mm each with opening of width 39mm were put into two halves of shear box of size 60mm x 60mm. This cylindrical samples were cut down into two and fixed in the circular opening of the wooden squares such that the separated parts are organised all over again on the shearing plane (i.e. Contact surface between two parts).The process was repeated for leftover samples.

4.7 Uniaxial compression test

The compression test mainly deals with the major principal stress, the loading is applied till the specimen fails under compression.

The specimen was readied as per the specifications given in ISRM 1981 which states

1. Cylindrical specimen with slenderness ratio between 2-3.
2. Specimen end to be levelled by 0.02 mm.
3. Specimen sides to be straighten by 0.3 mm along its length.
4. The ends must be parallel with the axis of the specimen.
5. The uniform diameter the length

The final specimen was inserted inside testing machine plates and was provided loading prior to its failing. The ultimate load was recorded and simultaneously measured the deformation with dial. After the brittle failure due to loading, the specimen showed minor decrease in load for further strain increment. The ratio of failure load and the specimen cross sectional area gives the uniaxial compressive strength. For other specimen, same procedure was repeated to obtain the strength.

4.8 Parameters studied

The experimental investigation was conducted to study the following aspects

1. The shearing behaviour of Plaster of Paris specimen.

2. The deformation of jointed specimen.

3. The effect of joint factor in the specimen strength.

4. A comparative assessment of joint with and without gouge fills.

4.9 Different Types of Joint Studied:

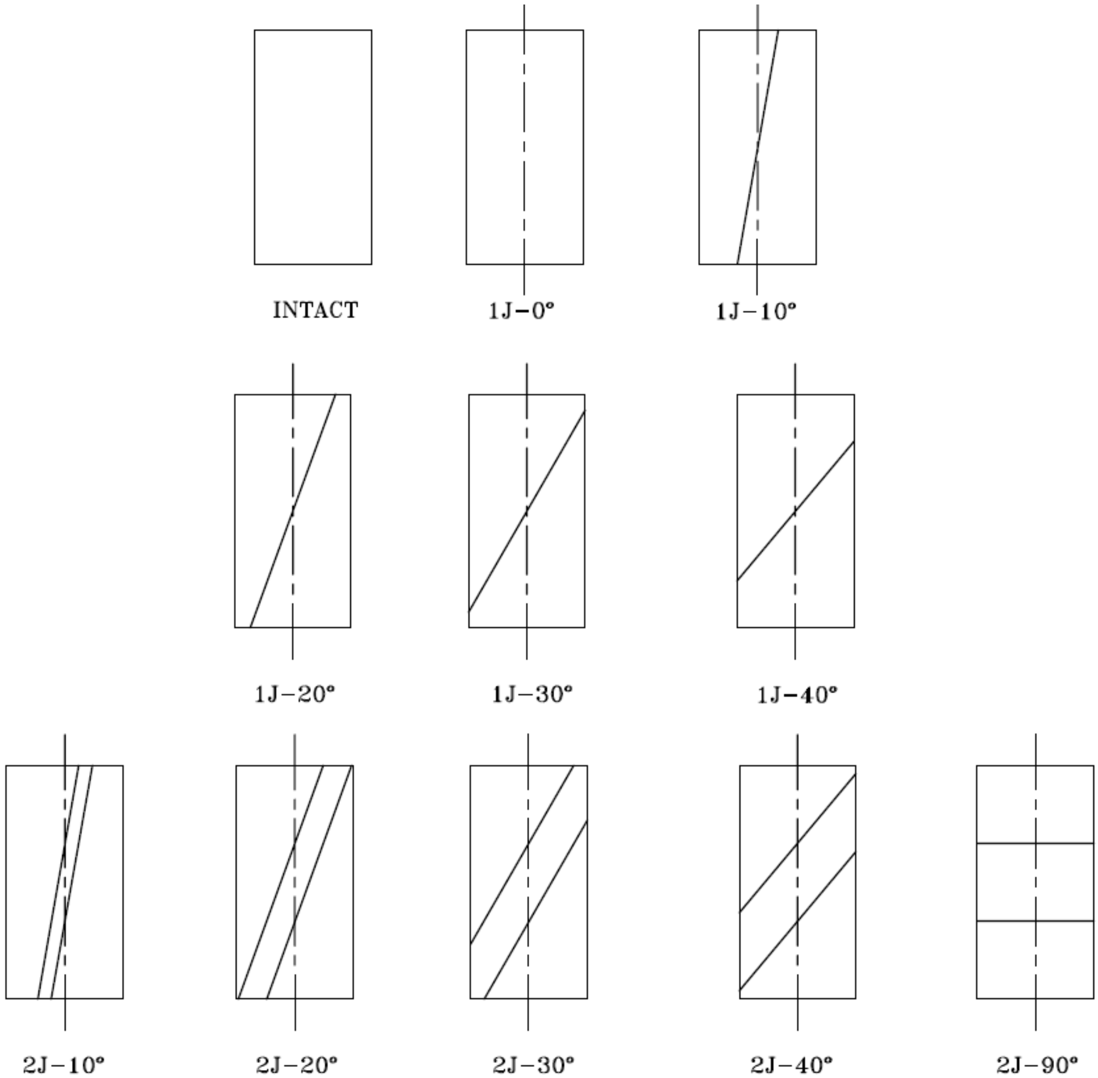

FIGURE-4.4 Different Jointed Specimen

Chapter 5

Result and Discussion

5.1 Optimum Moisture Content: to find the optimum moisture content first of all made lot of sample with different moisture content .and kept the sample for curing. Took the weight reading and when the weight of the sample was constant then the sample was fully cured. Then test the sample for uniaxial compressive strength samples made at different moisture content like 30%,32%,34%,36%.and measure the compressive strength of the sample.

Results obtained from the test was listed below

Table no-5.1

Tabulation for moisture content and UCS

Moisture Content (%)	UCS(MPa)
30	8.78
32	9.85
34	8.98
36	8.87

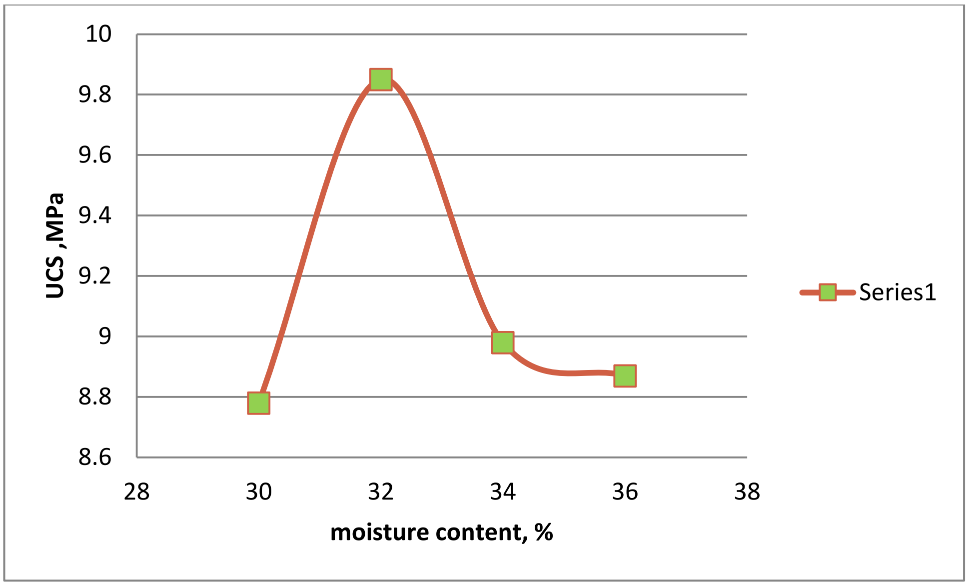

Figure-5.1 UCS and Moisture Content Variation

So from the above table we got the optimum moisture content where the uniaxial compressive strength is more so the 32% moisture content was the optimum moisture content. All the samples were made at this moisture content only. So the uniaxial compressive strength of the intact rock was found to be 9.85 MPa.

5.2 Results From XRD

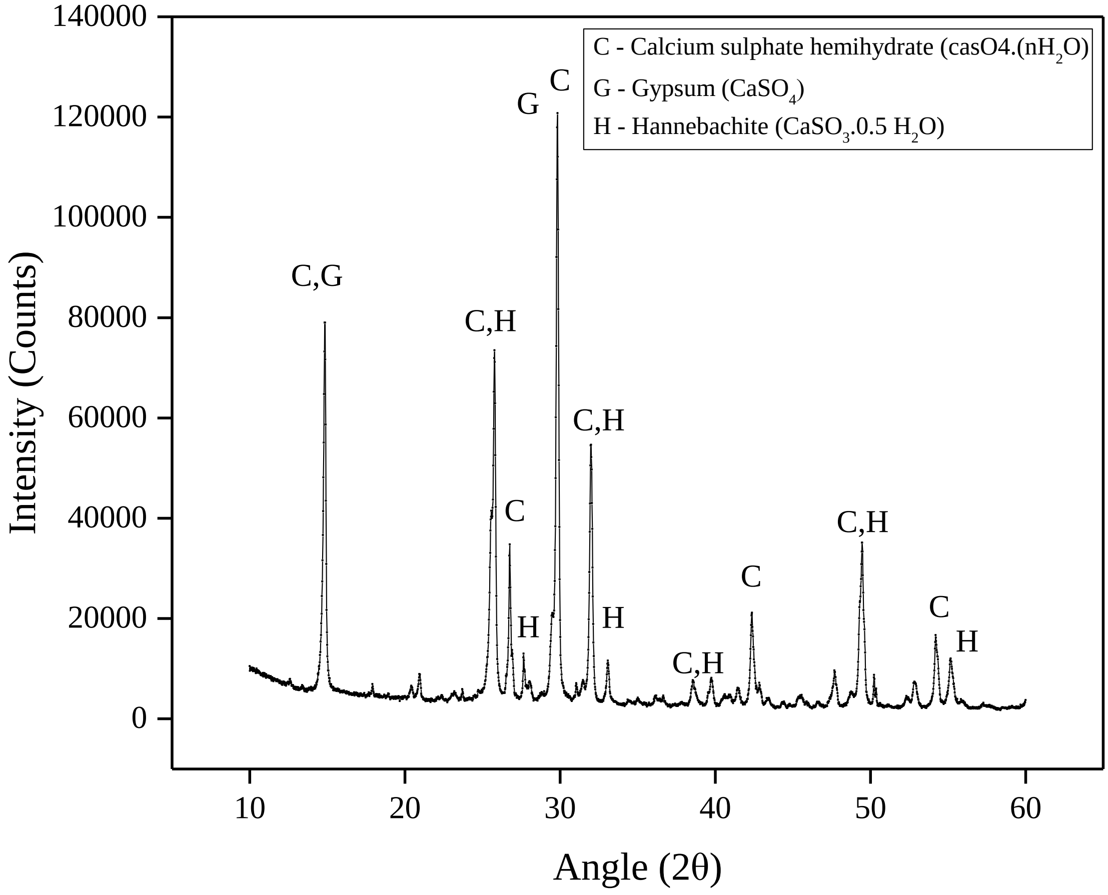

FIGURE-5.2 XRD Analysis of Plaster of Paris

5.3 Results From SEM:

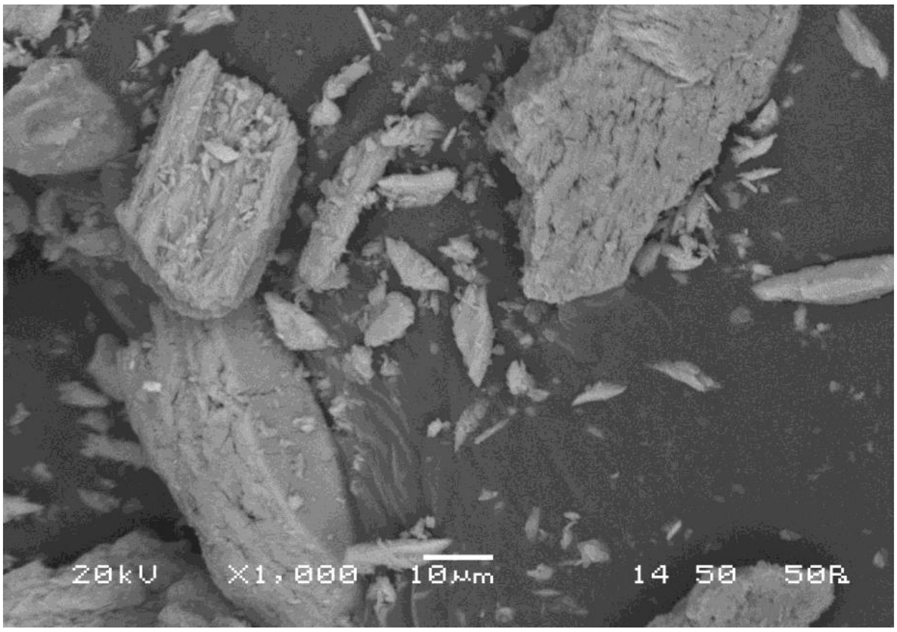

FIGURE-5 .3

Microstructure view of the plaster of paris specimen from the bottompart(X1000).

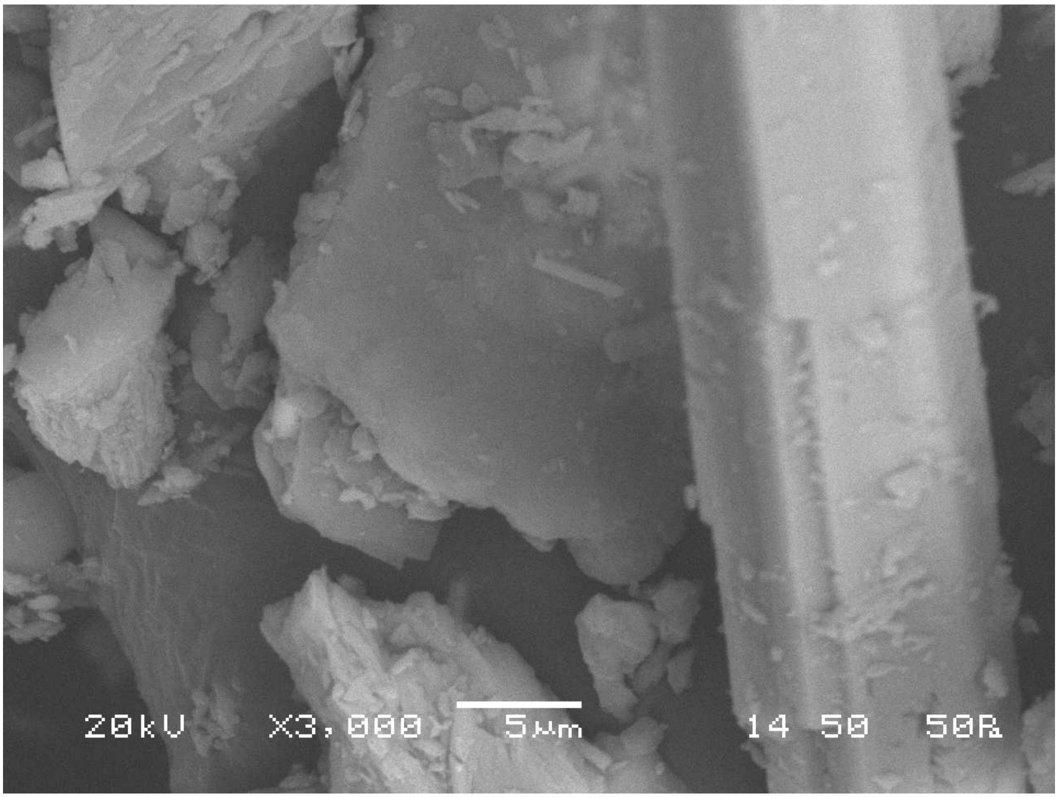

FIGURE-5.4

Microstructure view of the plaster of Paris specimen from the bottom part(X3000)

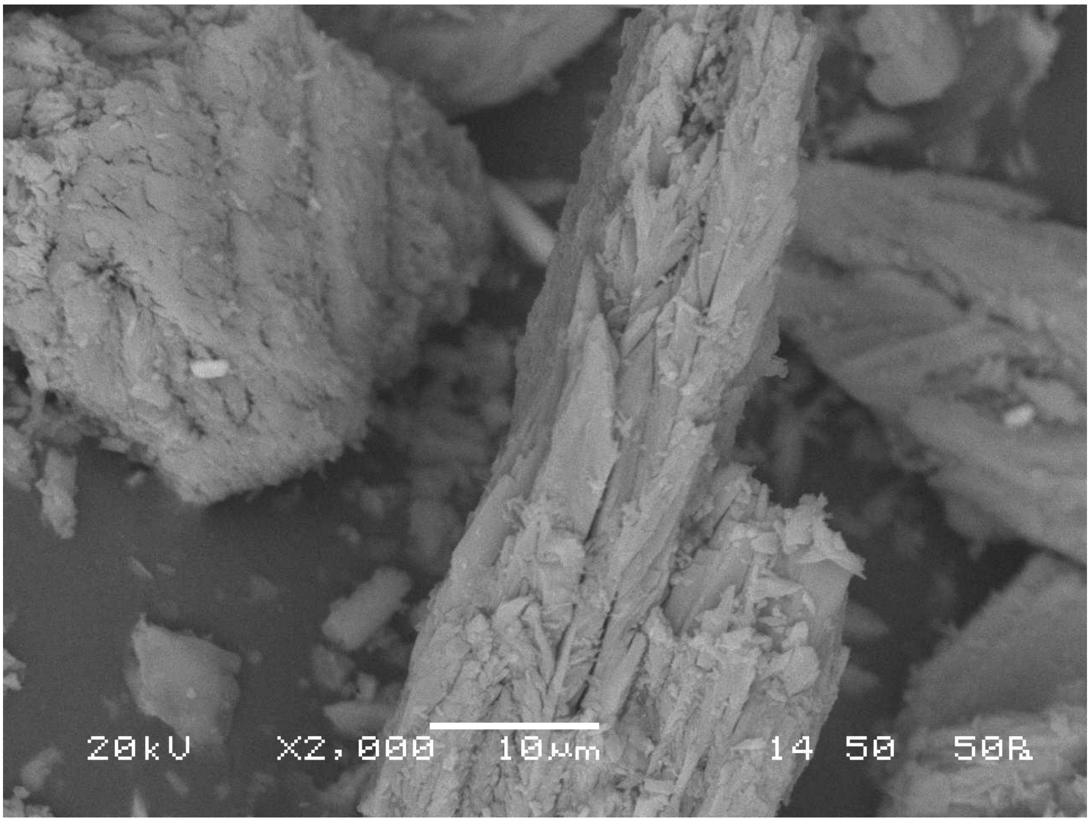

FIGURE-5.5

Microstructure view of the plaster of Paris specimen from the bottom part(X2000)

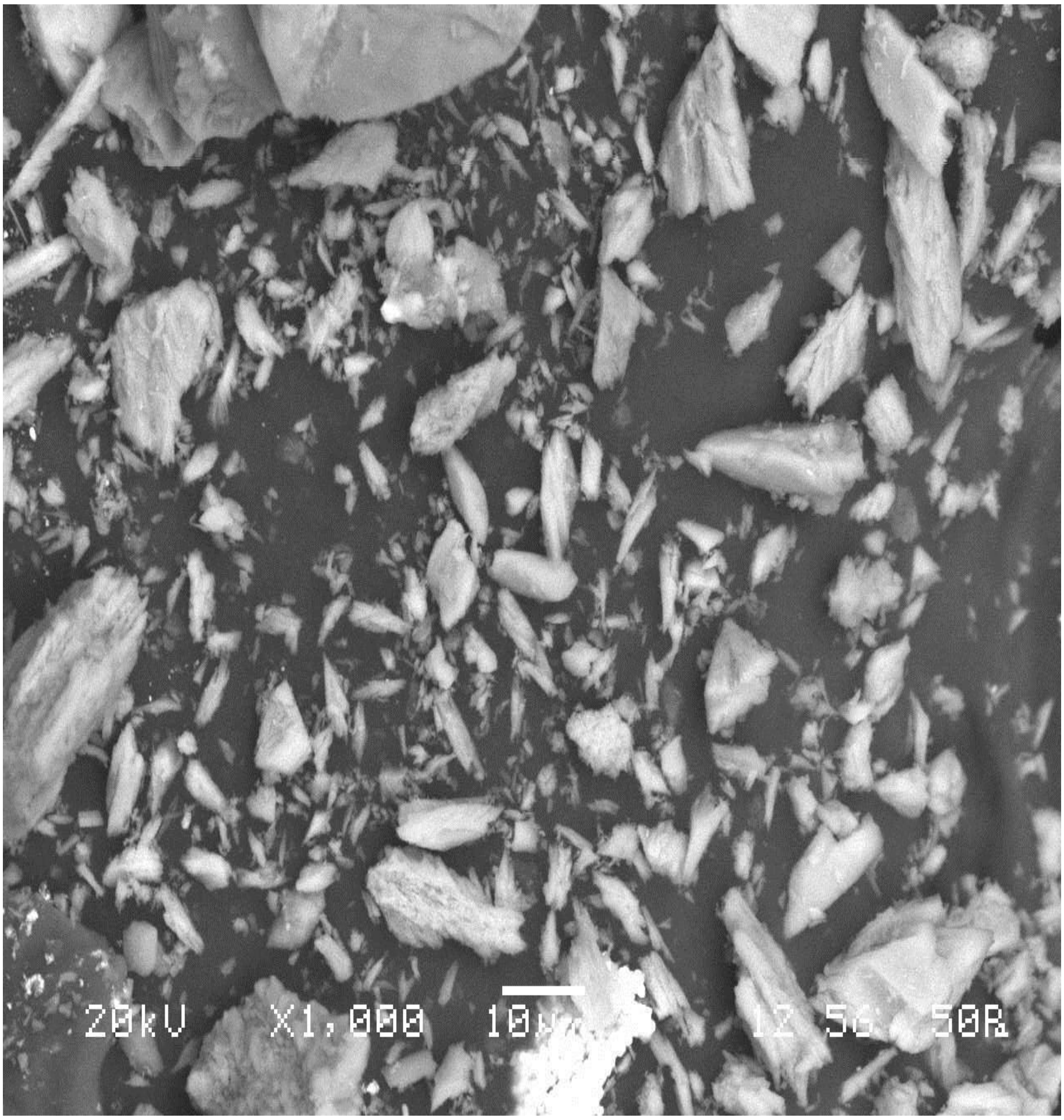

FIGURE-5.6

Microstructure view of the plaster of Paris specimen from the top part(X2000)

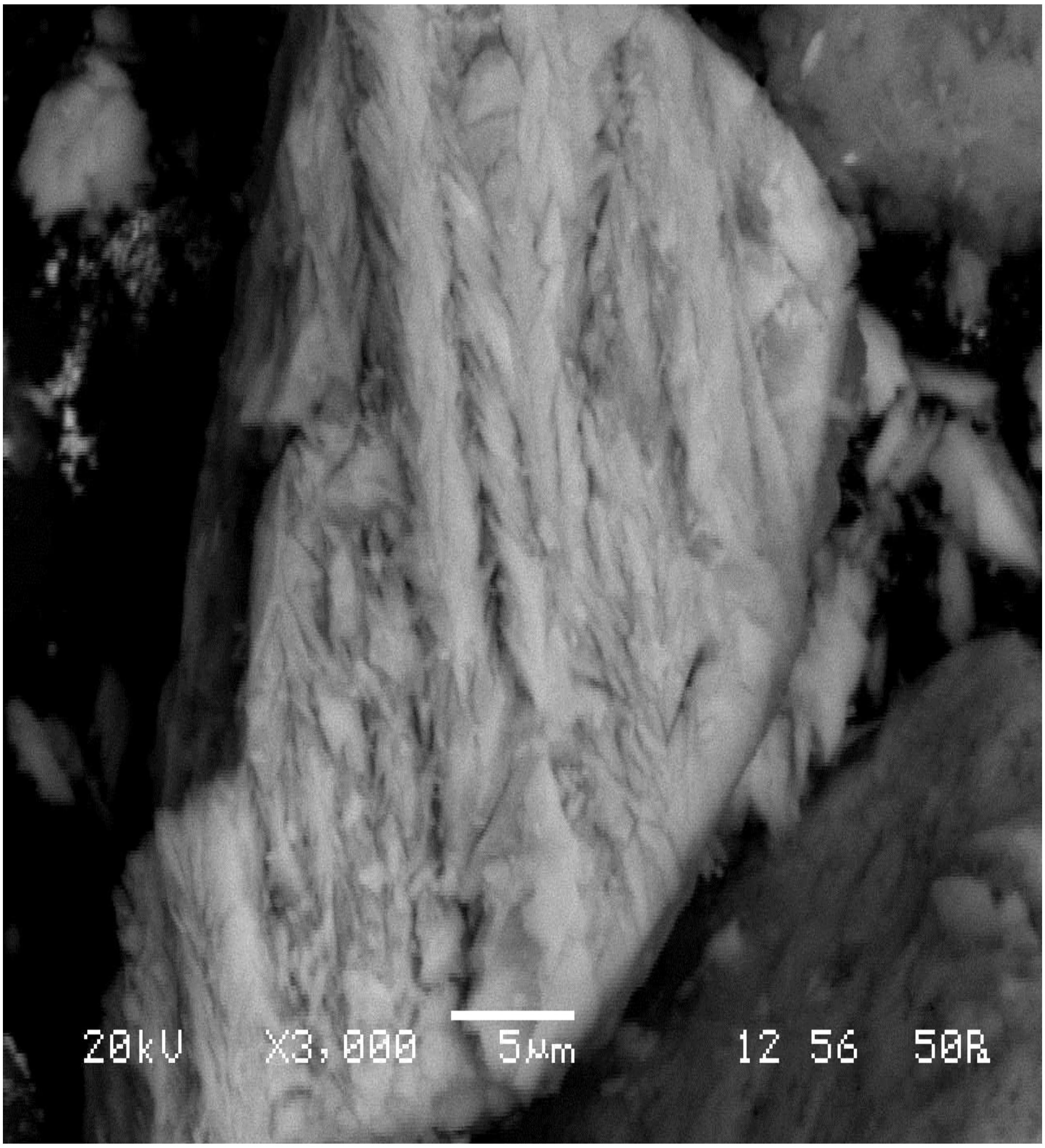

FIGURE-5.7

Microstructure view of the plaster of Paris specimen from the top part(X3000)

FIGURE-5.8

Microstructure view of the plaster of Paris specimen from the top part(X2000)

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5.4 Direct Shear Test Results

The tangent value of total angle of internal friction was called as the roughness parameter. This parameter was found from the direct shear test at various values of normal stress. The in the fig 5.9 we can see the variation between normal stress and shear test. there values are provided in the Table 5.2.The cohesion value (cj)and angle of internal friction was found to be 0.216MPa and 41˚ respectively. The roughness parameter obtained from the test was 0.9 for specimen made up of Plaster of Paris.

Table No-5.2

NORMAL STRESS(MPa)	SHEAR STRESS(MPa)
0.15	0.36
0.30	0.47
0.45	0.63

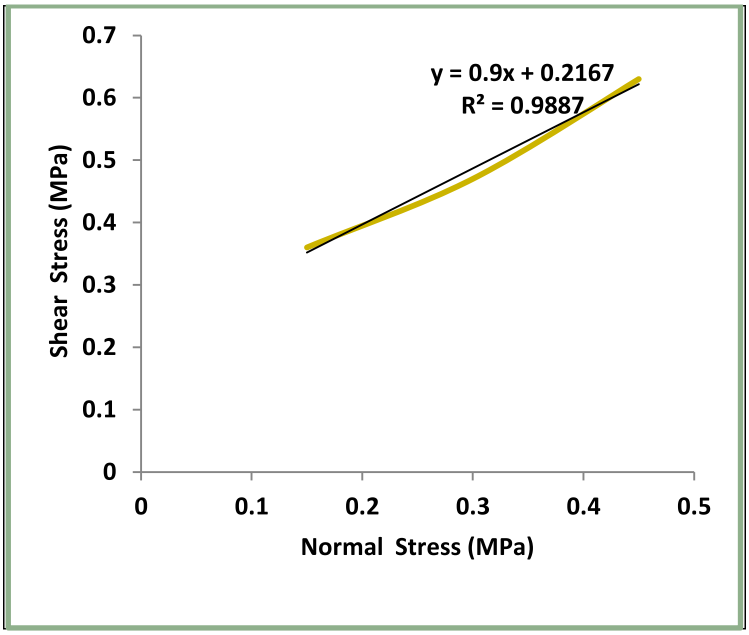

FIGURE-5.9 Variation of Normal stress with Shear stress

Table No-5.3

Tabulation for normal stress and shear stress

(single joint with gouge fill)

Normal stress MPa	Shear stress MPa
0.06	**0.05**
0.12	**0.09**
0.18	**0.12**

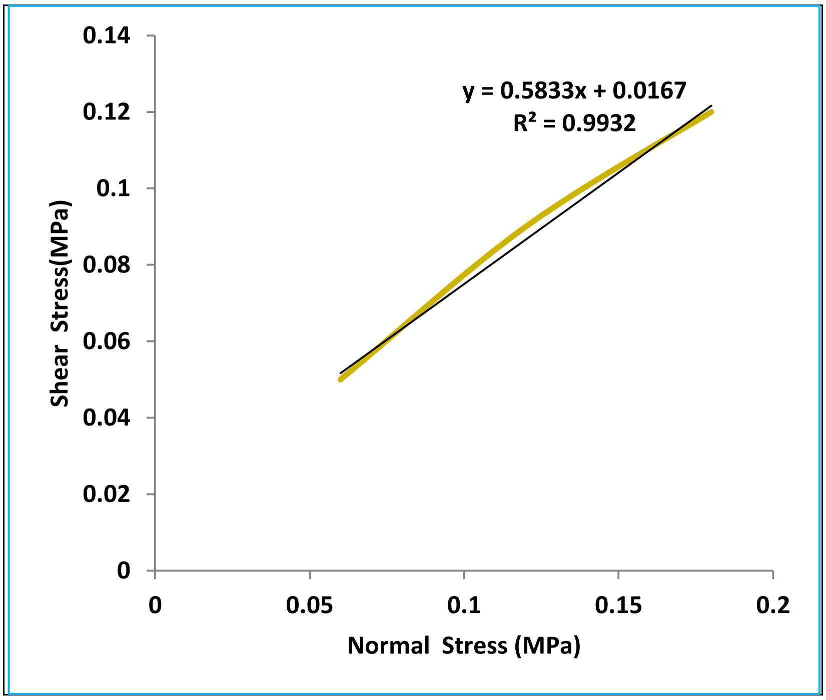

FIGURE-5.10 Variation with Normal stress with Shear stress

Table No-5.4

Orientation of joint β^0	Inclination parameter n
0	0.81
10	0.46
20	0.105
30	0.046
40	0.071
50	0.306
60	0.465
70	0.634
80	0.814
90	1

Table No-5.5

Values of Jn, J_f and σ_{cr} for jointed specimens (single joint)

β(angle in degree)	**Jn**	r	n	**J_f**	**J_f * 0.008**	**σ_{cr} (Arora)**
0	13	0.9	0.81	17.8326475	0.14266118	0.867047793
10	13	0.9	0.46	31.4009662	0.25120773	0.77786077
20	13	0.9	0.105	137.566138	1.1005291	0.332695008
30	13	0.9	0.046	314.009662	2.51207729	0.081099596
40	13	0.9	0.071	203.442879	1.62754304	0.196411558
50	13	0.9	0.306	47.2040668	0.37763253	0.685482346
60	13	0.9	0.465	31.0633214	0.24850657	0.779964736
70	13	0.9	0.634	22.7830354	0.18226428	0.833381063
80	13	0.9	0.814	17.7450177	0.14196014	0.867655839
90	13	0.9	1	14.4444444	0.11555556	0.890871078

Table No-5.6

Values of Jn, Jf and σcr for jointed specimens (Single joint with gouge fill)

β(angle in degree)	Jn	r	N	J_f	$J_f * 0.008$	σ_{cr} (Arora)
0	13	0.583	0.81	27.5289583	0.22023167	0.802332903
10	13	0.583	0.46	48.4749049	0.38779924	0.678548555
20	13	0.583	0.105	212.36625	1.69893	0.1828791
30	13	0.583	0.046	484.749049	3.87799239	0.020692326
40	13	0.583	0.071	314.062764	2.51250211	0.081065151
50	13	0.583	0.306	72.8707721	0.58296618	0.55824007
60	13	0.583	0.465	47.9536694	0.38362936	0.681383932
70	13	0.583	0.634	35.1710667	0.28136853	0.754750134
80	13	0.583	0.814	27.3936809	0.21914945	0.803201673
90	13	0.583	1	22.2984563	0.17838765	0.836618046

Table No-5.7

Values of Jn, Jf and σcr for jointed specimens (Double joint)

β(angle in degree)	Jn	r	n	J_f	$J_f * 0.008$	σ_{cr} (Arora)
10	26	0.9	0.46	62.8019324	0.50241546	0.605067378
20	26	0.9	0.105	275.132275	2.2010582	0.110685968
30	26	0.9	0.046	628.019324	5.02415459	0.016577145
40	26	0.9	0.071	406.885759	3.25508607	0.0385775
50	26	0.9	0.306	94.4081336	0.75526507	0.469886046
60	26	0.9	0.465	62.1266428	0.49701314	0.608344989
70	26	0.9	0.634	45.5660708	0.36452857	0.694523996
80	26	0.9	0.814	35.4900355	0.28392028	0.752826655
90	26	0.9	1	28.8888889	0.23111111	0.793651278

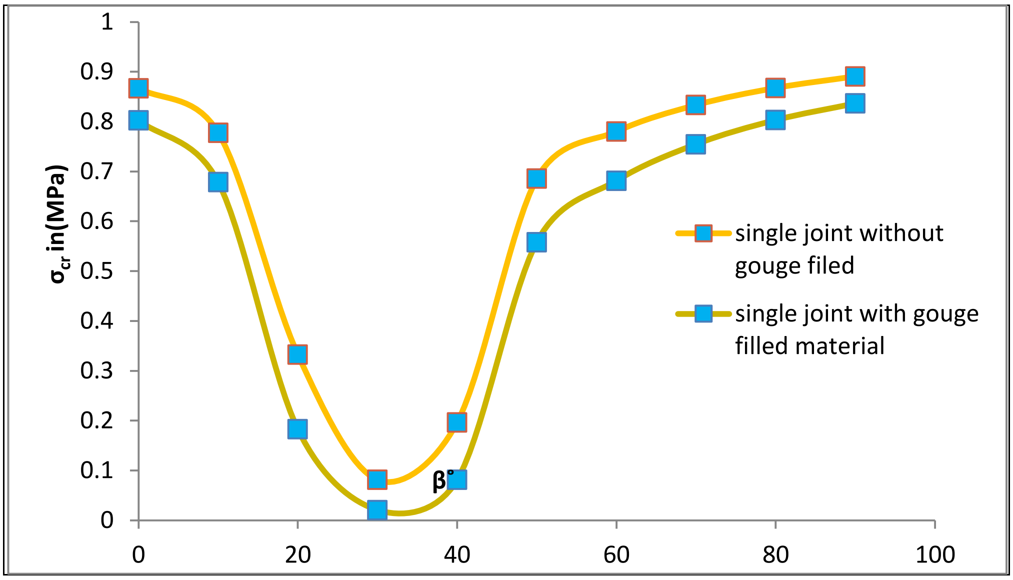

FIGURE -5.11 Variation of Angle of Joint with Compressive Strength Ratio

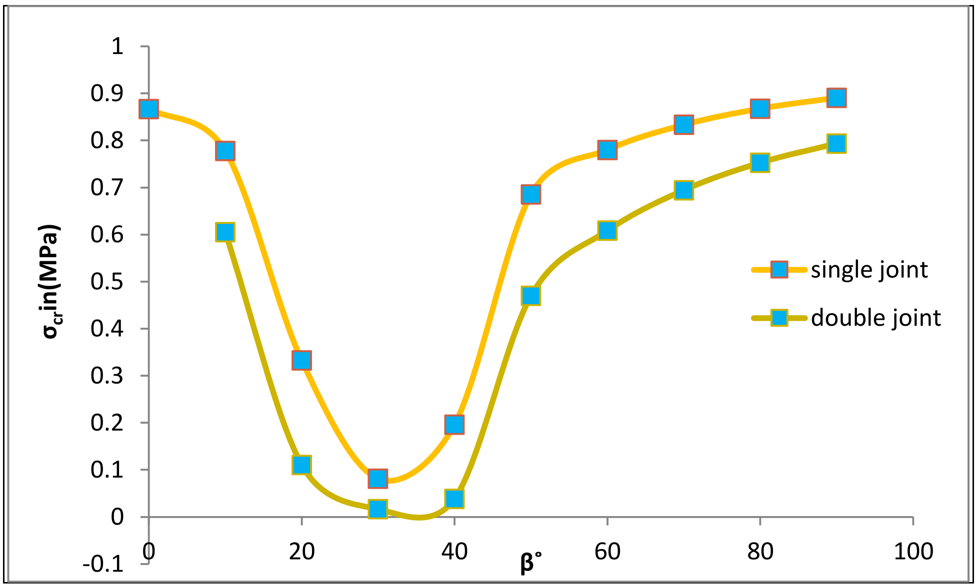

FIGURE-5.12 variation of orientation angle of joint with compressive strength ratio

Table No-5.8

Values of σ_{cj} for different joint Orientation angle, β (single joints with and without gouge fill)

β (angle in degree)	Single joint(σ_{cj})	Single joint with gouge fill(σ_{cj})	Decrease in strength
0	7.6	6.67	0.93
10	6.1	5.6	0.5
20	2.35	1.55	0.8
30	0.66	0.16	0.5
40	1.78	0.38	1.4
50	4.96	2.3	2.66
60	5.8	4.98	0.82
70	6.69	5.2	1.49
80	7.15	6.36	0.79
90	7.36	6.8	0.56

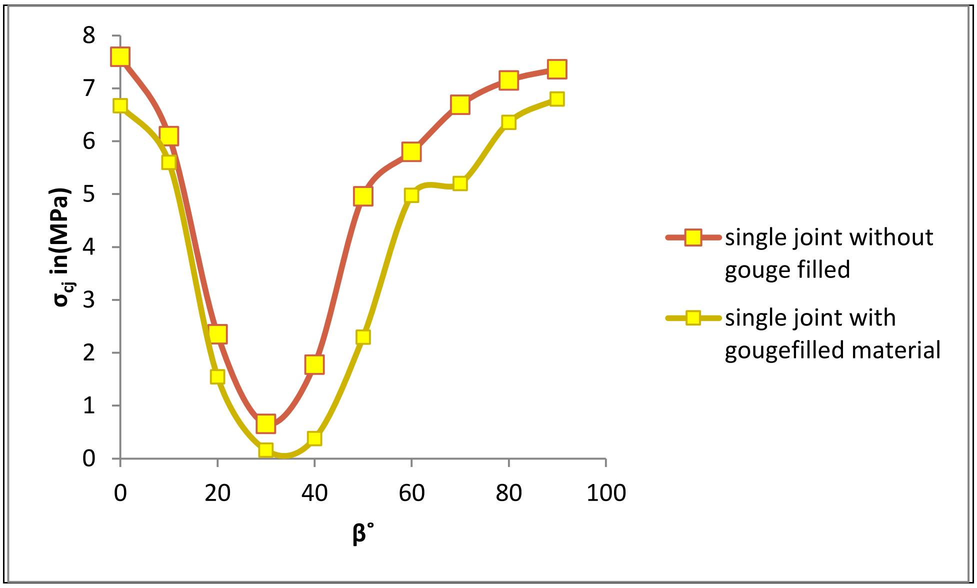

FIGURE-5.13 Variation of σ_{cj} of Single Joint with Gouge fill and without Gouge filled with Orientation angle

Table No-5.9

Values of σ_{cj} for different joint Orientation angle,β^0

β (angle in degree)	Single joint(σ_{cj})	Double joint(σ_{cj})	Decrease in strength
10	6.1	4.95	1.15
20	2.35	1.56	0.79
30	0.66	0.05	0.61
40	1.78	1.06	0.72
50	4.96	3.25	1.71
60	5.8	4.41	1.39
70	6.69	4.62	2.07
80	7.15	5.7	1.45
90	7.36	6.81	0.55

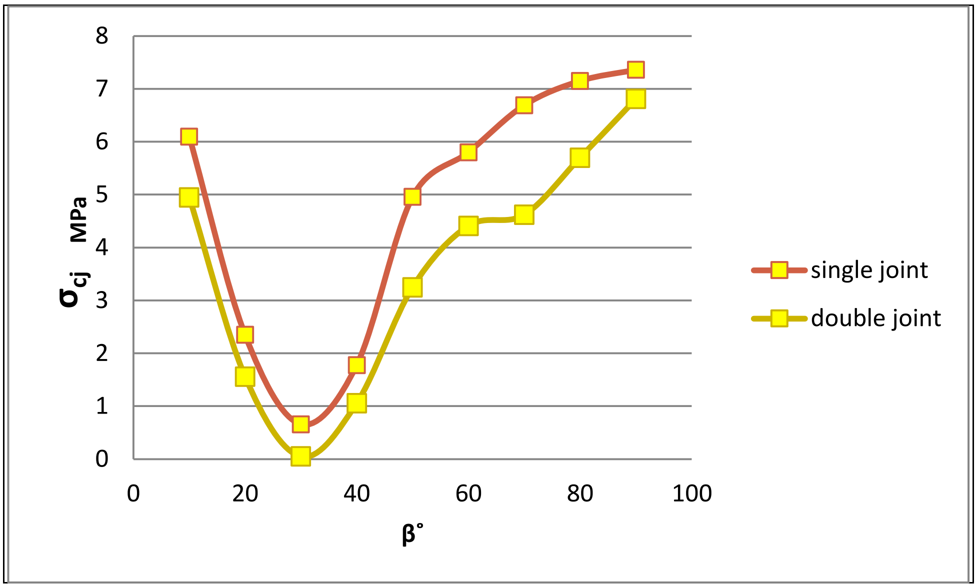

FIGURE-5.14 **Variation of σ_{cj} with Orientation Angle β°**

Table No-5.10

Values of σ_{cj} of single joint and intact rock for

orientation angle β°

β (angle in degree)	Single joint(σ_{cj})	Intact rock strength(σ_{ci})	Compressive strength ratio(σ_{cr})
0	7.6	9.85	0.771574
10	6.1	9.85	0.619289
20	2.35	9.85	0.238579
30	0.66	9.85	0.067005
40	1.78	9.85	0.180711
50	4.96	9.85	0.503553
60	5.8	9.85	0.588832
70	6.69	9.85	0.679188
80	7.15	9.85	0.725888
90	7.36	9.85	0.747208

Table No-5.11

Values of σcj for single joint with gouge fill and Intact rock for Orientation angle,β °

β (angle in degree)	double joint(σ_{cj})	Intact rock strength(σ_{ci})	Compressive strength ratio(σ_{cr})
10	4.95	9.85	0.502538
20	1.56	9.85	0.158376
30	0.05	9.85	0.005076
40	1.06	9.85	0.107614
50	3.25	9.85	0.329949
60	4.41	9.85	0.447716
70	4.62	9.85	0.469036
80	5.7	9.85	0.57868
90	6.81	9.85	0.691371

Table No-5.12

Values of σcj for double joint with gouge fill and

Intact rock for Orientation angle β°

β (angle in degree)	Single joint with gouge fill(σ_{cj})	Intact rock strength(σ_{ci})	Compressive strength ratio(σ_{cr})
0	6.67	9.85	0.677157
10	5.6	9.85	0.568528
20	1.55	9.85	0.15736
30	0.16	9.85	0.016244
40	0.38	9.85	0.038579
50	2.3	9.85	0.233503
60	4.98	9.85	0.505584
70	5.2	9.85	0.527919
80	6.36	9.85	0.645685
90	6.8	9.85	0.690355

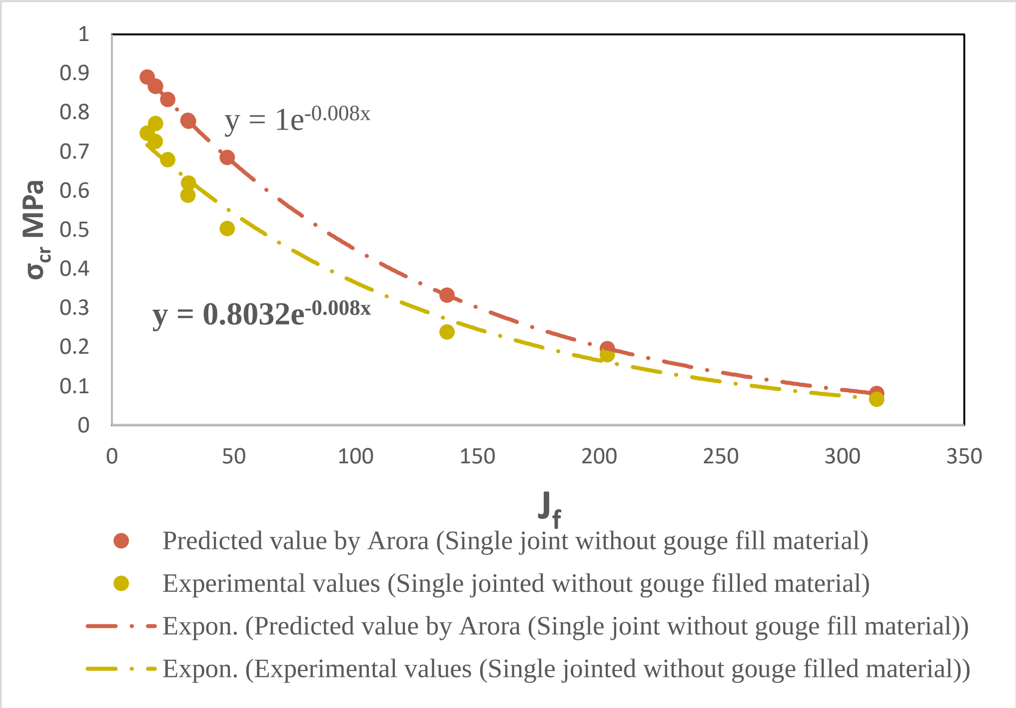

FIGURE-5.15 Variation of predicated value of compressive strength ratio given by Arora With experimental values(single joint without gouge filled material)

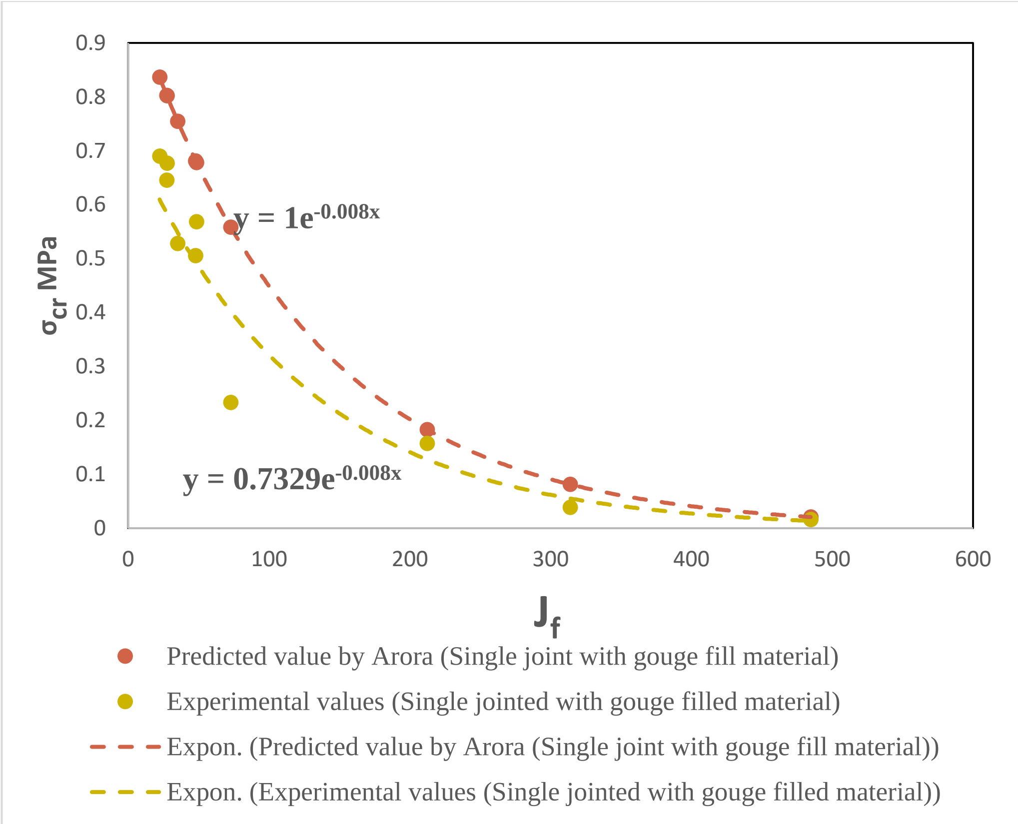

FIGURE5.16 Variation of predicated value of compressive strength ratio given by Arora with Experimental values (single joint without gouge filled material)

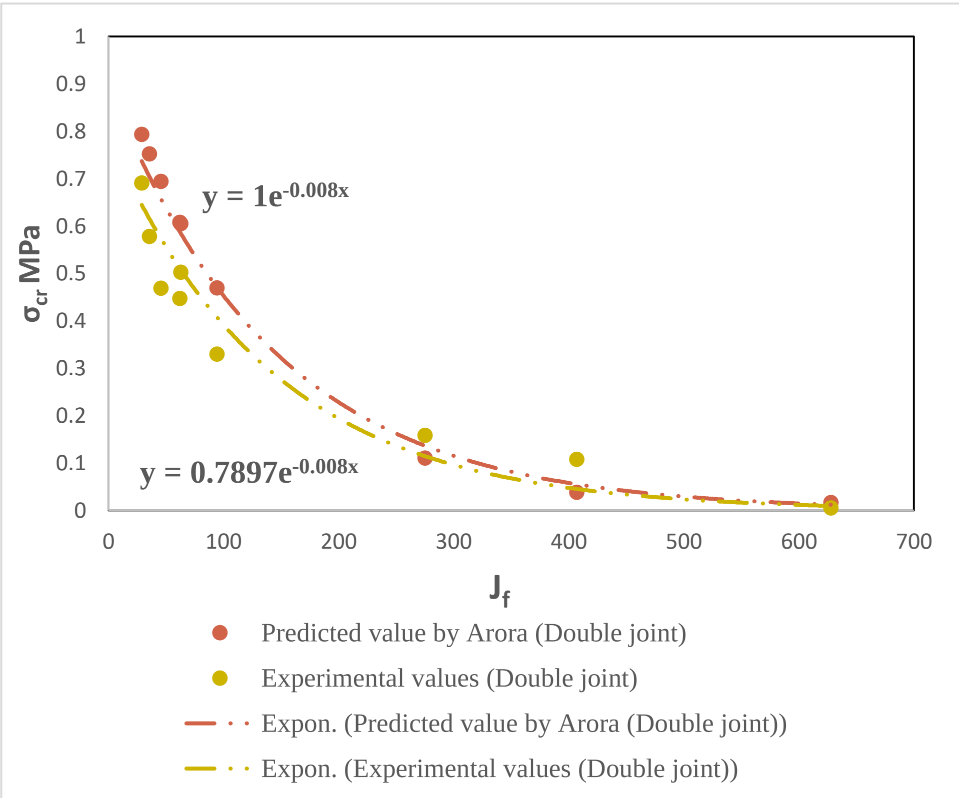

FIGURE-5.17 Variation of predicated value of compressive strength ratio given by Arora with Experimental values (Double joint)

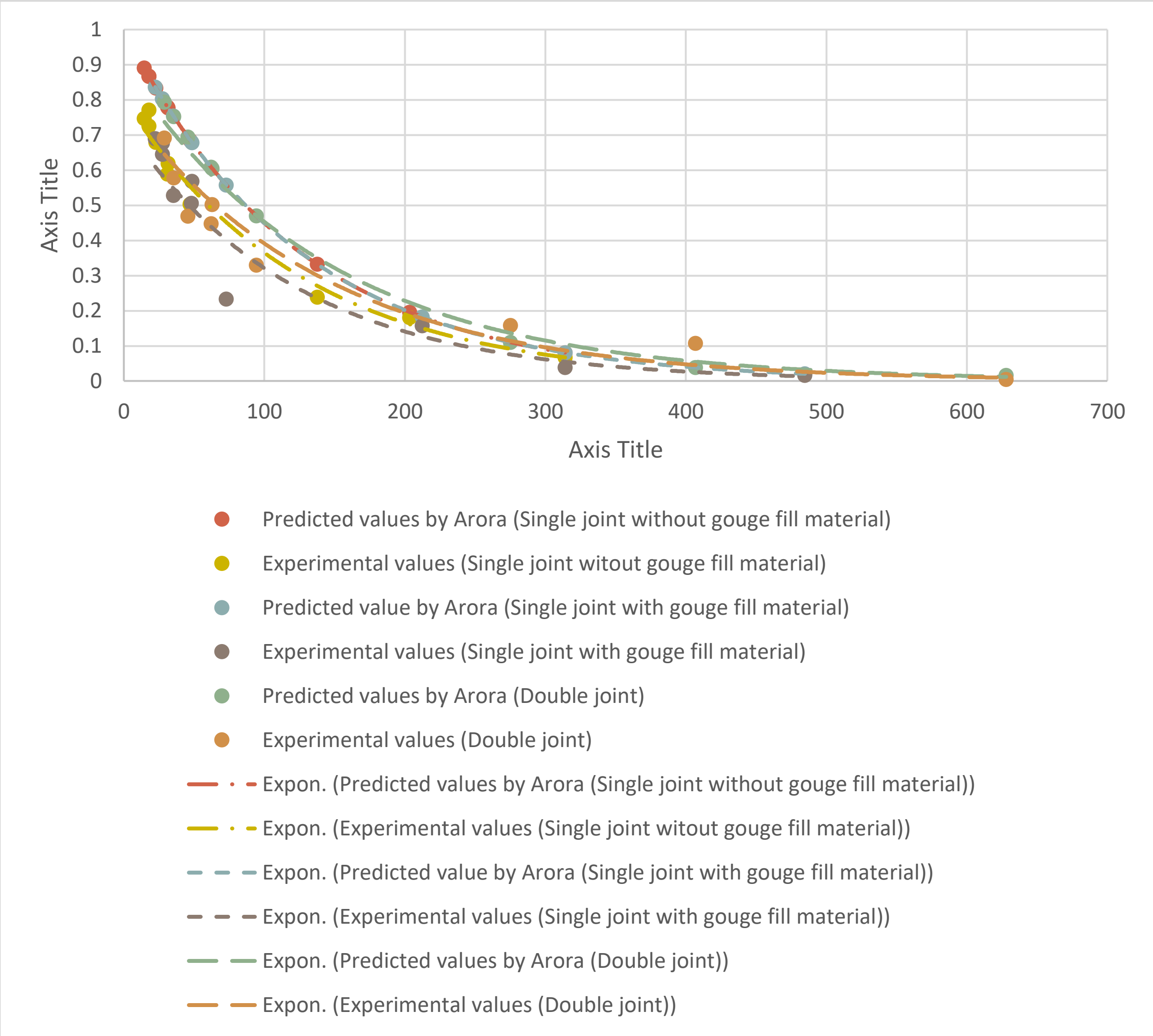

FIGURE-5.18

Variation of predicated value of compressive strength ratio given by Arora with Experimental values with joint factor

Chapter 6

Conclusion

Based on the experimental investigation on intact and gouge filled joints the following conclusions are drawn.

1. The uniaxial compressive strength of the intact specimen was found to be 9.85MPa
2. The empirical relationship given by Arora for predication of compressive strength of jointed rock.

is given by.

$\sigma_{cr} = e^{-0.008*Jf}$

Where $\sigma_{cr} = \sigma_{cj} / \sigma_{ci}$,

$J_f = (J_n/(n \times r))$,

σ_{cj} = uniaxial compressive strength of jointed rock

σ_{ci} = uniaxial strength of intact rock .

J_n = joint frequency

n = inclination parameter depending on the orientation of the joint.

r = roughness parameter depending on the joint condition.

Our experimental values of compressive strength are just similar like that of predicated values of Arora.

3. The strength of jointed specimen depends on the joint orientation β˚ with respect to the direction of major principal stress .The strength at $\beta=30^0$(for single jointed specimen) was found to be 0.66 MPa which is minimum and the strength at $\beta = 90^0$(for single jointed specimen) was found to be 7.6 MPa which is maximum.

4. As the number of joints increases, the uniaxial compressive strength of plaster of Pairs specimen decreases.

Scope of future work

1. Studies should be possible for different joints at different angle of orientation

2. The impact of rate of loading, temperature and confining pressure on the quality attributes can be contemplated.

3. Strength and deformation behavior of jointed specimens can be done under triaxial loading conditions for samples with single or multiple joints.

4. Strength and deformation behavior of jointed specimens under triaxial loading conditions can be studied with gouge filled joints.

5. Prediction of strength and deformation behavior of specimens with any arbitrary orientation can be done by using artificial neural network with the help of these data's mentioned in the study.

6. Different theories can be used for developing numerical models and the results can be compared with the experimental results to reach at the best possible numerical model.

7. we can analyses the different experimental results by using different software.

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